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GB 2365905 A US 5609442 A

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UK CL (Edition T) B7A AAAQ, E1H HB, F1T TDC
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Other: Online EPODOC JAPIO WPI

(54) Abstract Title

Floating offshore wind turbine

(57) A floating support structure comprises a watertight hull 1, a gravity or suction foundation comprising one or more components 7 located on the seabed and one or more buoyancy devices 4 connected to said watertight hull and configured to provide excess buoyancy and additional stability. The watertight hull and buoyancy device assembly is tethered to the foundation such that the excess buoyancy is manifested as a force in the tethers. A telescopically extendable shaft 3 extends upwardly from the hull and has a hoist 9 located at the shaft top. A wind turbine 8 may be located at the top of the shaft while a generator may be located in the hull. The structure can be towed with the shaft retracted and subsequently extended and grouted following installation. A method of connection several of the structures using horizontal connectors is also disclosed.

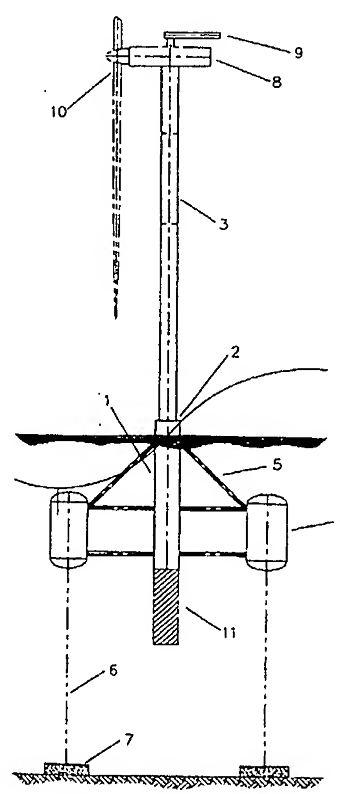

FIGURE 1

The claims were filed later than the filing date but within the period prescribed by Rule 25(1) of the Patents Rules 1995.

The print reflects an assignment of the application under the provisions of Section 30 of the Patents Act 1977.

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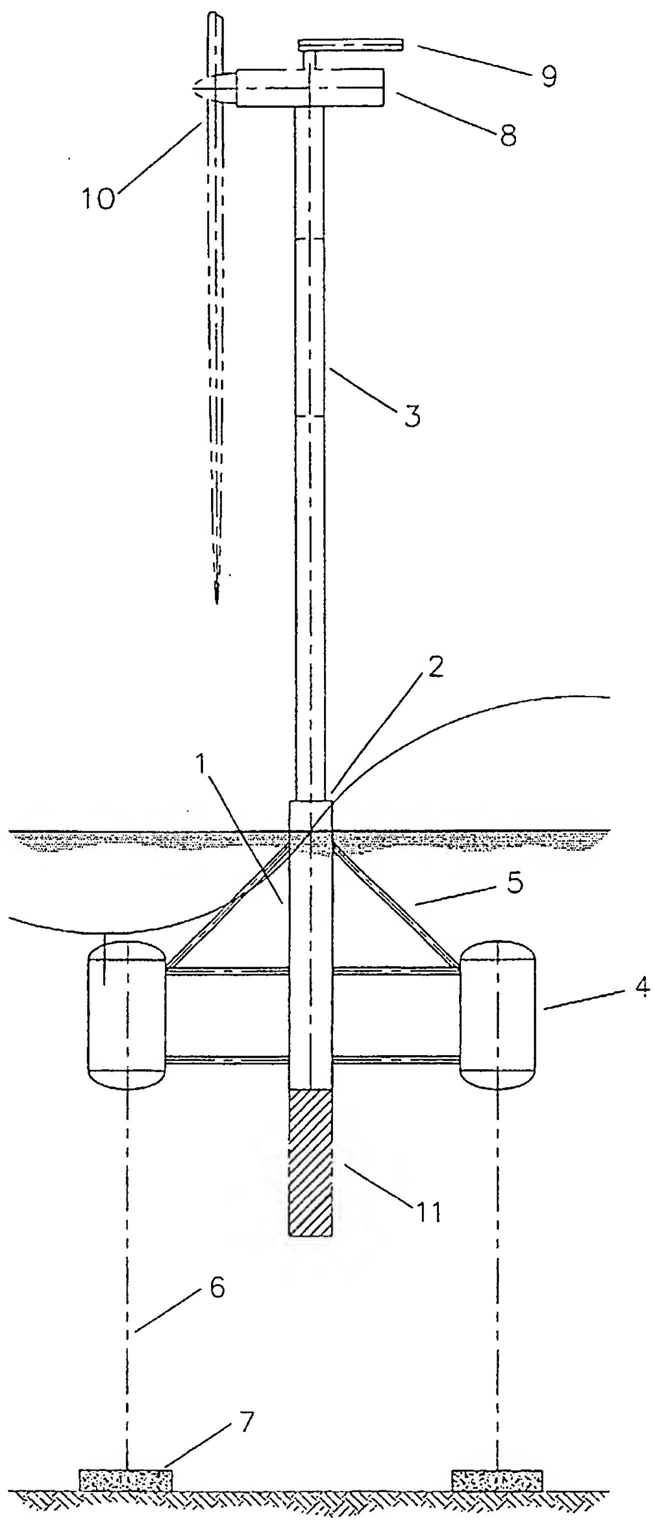

FIGURE 1

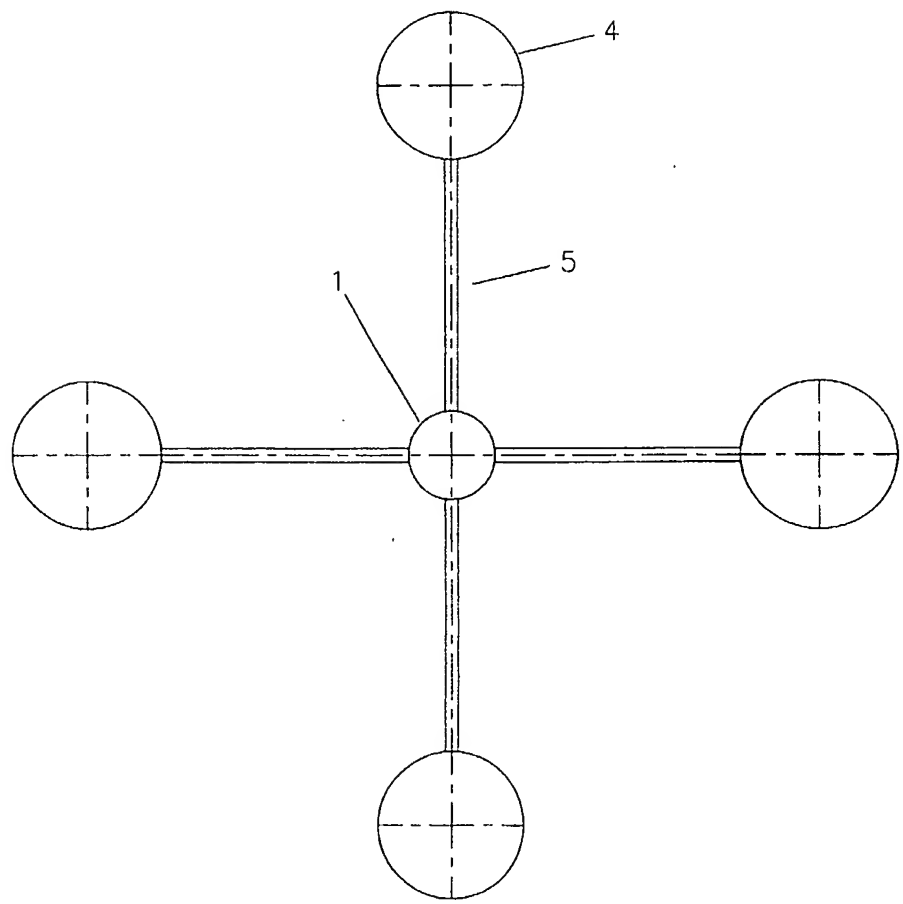

FIGURE 2

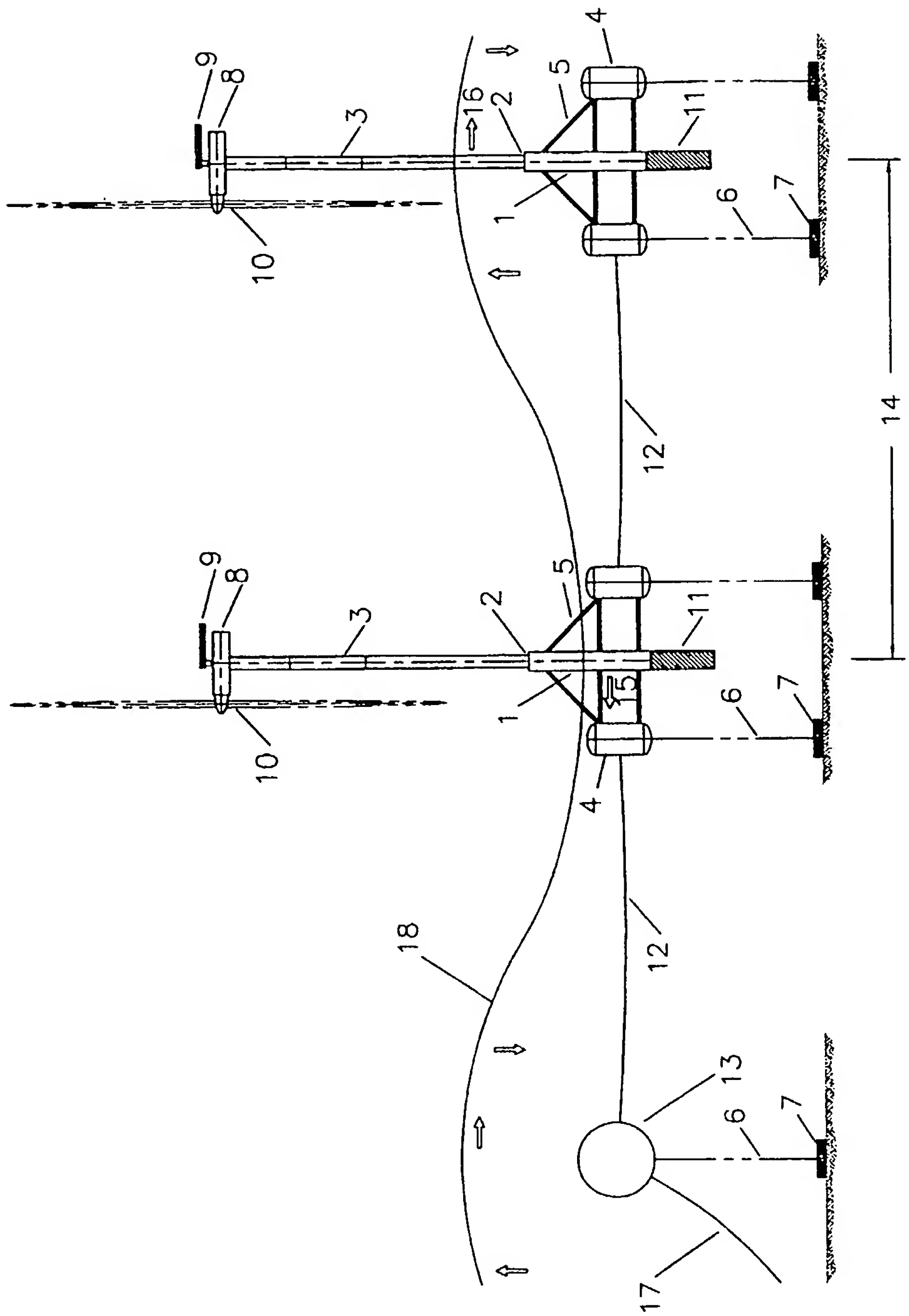

FIGURE 3

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FLOATING OFFSHORE WINDTOWER

This invention relates to offshore structures for wind turbines.

Currently the foundation structures used for housing wind turbines offshore require that the turbine support structure is rigidly fixed to the seabed foundation prior to installation or that the foundation is pre-installed and the turbine rigidly fixed to it in a separate operation. As the water depth increases the rigidly connected foundation becomes uneconomical due to the large volume of material required to resist lateral forces and support the wind turbine.

We have now devised a floating wind tower support structure for offshore use with a wind turbine and installation method, which obviates the above problem.

According to the present invention there is provided a floating wind turbine or general equipment installation and support structure comprising a watertight hull formed of concrete, ferrous cement, fibre-reinforced concrete, steel or other suitable material, a gravity or suction foundation comprising one or more components located at or on a lakebed or seabed, one or more buoyancy devices connected to said watertight hull and configured to provide excess buoyancy and additional stability, the watertight hull and buoyancy device assembly being tethered to said foundation such that the excess buoyancy is manifested as a force in the tethers, said tethers thus remaining taut and providing additional stability, and a shaft which extends upwardly from the hull, said shaft being telescopically extendable, with a hoist located at the shaft top.

Preferably the buoyancy devices consist of cylindrical vessels with domed ends, and are attached to the structure with steel tubular sections. This allows modular construction and sizing for site specific criteria. Air or gas pressurisation of the buoyancy devices may be used to ensure internal pressure is greater than external, thus eliminating the requirement for additional stiffeners, and thereby reducing structural weight and cost.

In an alternative embodiment the excess buoyancy is provided with a single hull to which the shaft and tethers are attached. In this case the tethers may be connected by means of horizontal outriggers to increase righting moments in the buoy system.

Ballast containers can be fitted to the mast at various levels to allow for control of vibration of natural frequencies if required.

Preferably the foundation comprises a gravity base or suction caissons, and can be used to aid flotation during tow out and installation. Also, the foundation can provide a template / guide to aid tether installation.

The tethers can be used to lower the foundation to the lakebed or seabed during installation.

Preferably, lengths of chain are attached between the tethers and winches on the structure to allow for variations in water depth during installation.

Preferably a wind turbine is located at the top of the shaft prior to installation.

However, in alternative embodiments the structure can be used to install and support other equipment for use offshore, for example telecommunications equipment, pollution detection equipment, gas flaring equipment, or monitoring equipment.

Another embodiment has a water turbine assembly suspended under the hull, with additional support provided by slidable linkages connected from the turbine to the tethers. The water turbine is driven by current and wave loading, and can be raised or lowered to facilitate maintenance.

Preferably the shaft is fully retracted during tow out, and foundation ballast and installation operations.

In a further embodiment an additional tubular shaft (lower) is designed to be fitted with ballast and to be extendable beneath the hull thus causing the centre of gravity of the structure to be lowered, and thus increasing stability through viscous drag damping and increased metacentric height. Preferably the annular space between the tubular shaft and the hull can be grouted to provide a rigid connection for the telescopic shafts once in the fully extended position for both the upper and lower shafts. Alternatively, clamping devices may be used to facilitate subsequent lowering of the mast for maintenance or removal.

In another embodiment steel or other suitable material rods or wires are connected parallel to the tubular mast structure (extended shaft) attached to spacers located at several positions along the axis of mast. These rods or wires may be pre-stressed. This strengthens the mast allowing the use of smaller steel sections with a consequent weight reduction and improved stability. A tensioning device may additionally be used with this embodiment to cyclically pre-stress the support rods. A load detection device may also be employed in conjunction with the tensioner such that the tension is adjusted relative to the external applied load to reduce mast motion or stress levels and improve fatigue life. The tensioning device may be hydraulic, electrically operated or mechanical.

In one embodiment of the invention a generator is located in the submerged hull and rotated remotely by hydraulic drive from the rotor. This removes weight from the top of the structure and aids stability during tow out, installation, and operation. A further modification is to have the generator mounted with its axis vertical in the hull to enable the use of a very large diameter generator with subsequent improved power efficiency.

During installation the rotor blades are normally fixed to the turbine axle subsequent to the installation of the support structure and to the shaft being partially or fully extended.

In an alternative embodiment the rotor hub and blades are hinged to the top of the shaft at a horizontal angle enabling said hub and blades to be fitted to the structure prior to tow out and foundation installation. The hoist is then used to position the rotor hub and blades in the desired vertical position after foundation installation and shaft extension operations.

In another embodiment the blades are hinged to the rotor hub and a hydraulic jacking mechanism is provided such that the blades can be rotated into horizontal alignment. This ensures that the blades are clear of the water surface and allows them to be fitted to the structure prior to tow out and installation. After installation and shaft extension the blades are rotated into the desired alignment by releasing the hydraulic jacks.

Also, in accordance with this invention there is provided a method of combining two or more floating wind turbine or general equipment installation and support structures to enhance dynamic stability in the combined system, the structures each having a watertight hull, a gravity or suction foundation located at or on a lakebed or seabed, one or more buoyancy devices connected to said watertight hull, the watertight hull and buoyancy device assembly being tethered to said foundation such that excess buoyancy is manifested as a force in the tethers, said tethers thus remaining taut and providing additional stability, and a shaft which extends upwardly from the hull, said shaft being telescopically extendable, the method comprising the interconnection of one or more of the structures by horizontal or nearly horizontal flexible connectors, said connectors having a stiffness and pretension selected to ensure that horizontal restraining forces acting between the floating structures are transferred through the connectors in partial or complete opposition to the environmental loadings to which each structure is independently subject.

It is a requirement of the invention that adjacent connected structures be placed at such a distance as to be subject as far as possible to a differing phase of the wave cycle at the same instant i.e. water particle velocity on each structure will have a different relative motion.

In an alternative embodiment of the method an anchor structure is used to reduce the overall motions of the combined support structures. This consists of one or more mid water float chambers tethered to the seabed and tethered to one or more of the floating support structures.

Another embodiment of the method uses damping devices, e.g. springs, chains attached to the tethers between support structures or anchor and support structures in order to influence the stiffness and motions of the system.

A specific embodiment of the invention will now be described by way of example only and with reference to the accompanying drawings in which: -

Figure 1 shows in vertical cross section the floating wind turbine or general equipment support structure on location with the shaft fully extended.

Figure 2 shows the floating wind turbine or general equipment support structure in plan view.

Figure 3 shows two floating wind turbine support structures combined using a flexible tether, with additional dynamic stability provided using a mid-water anchored structure.

Referring to the drawings the structure comprises a watertight hull 1, which is formed to include a tubular opening 2 to allow for insertion of a telescopic shaft 3. A plurality of buoyancy compartments 4 provides excess buoyancy (above that required for flotation), and is spaced to provide additional stability to the floating structure. The buoyancy compartments 4 are attached to the hull 1 with steel beams 5.

The buoyancy compartments 4 are provided with tether termination plates (not shown) so that tethers 6 can be attached. Suction caissons 7 are installed on the seabed and the tethers 6 are attached between said caissons 7 and the buoyancy compartments 4.

A turbine package 8 is located at the top of the shaft 3. Also, an extendable tubular hull 11, which can be filled with ballast, is shown beneath the hull 1.

The structure is set up for operation by extending the telescopic shaft 3 to its fully extended position as shown in Figure 1. Once the shaft 3 has been locked in position a hoist 9, located at the top of the shaft 3, is used to lift and install the rotor hub and blades 10. Platforms (not shown) are provided for access to grout operations, for ease of maintenance, and checks.

The telescopic shaft, 3, is raised using a jacking system with frame and pins (not shown) or by pressurising the hull 1 interior and pumping (not shown). In an alternative embodiment (not shown) the tubular opening 2 extends to the hull 1 bottom so that pressure can be applied within the opening 2, to raise the shaft 3. Once raised the shaft 3 is grouted into position.

During tow out the shaft 3 is retracted and the caissons 7 are used to provide buoyancy. On reaching location the caissons 7 are attached to the tethers 6 and ballasted to the seabed using the tethers 6 as an installation aid to lower them. Lengths of chain are attached to the tethers 6 at one end and a winch (not shown) at the other end. The caissons 7 are then partially ballasted and winched to the seabed. The caissons 7 are then pumped out to facilitate seabed penetration and the chains winched in to lower the hull 1 to the desired position. The chains are subsequently fastened to the buoyancy compartments 4. Then the shaft 3 is raised.

Figure 3 shows how additional structures can be combined using one or more flexible tethers 12. The windtower support structures are given additional dynamic stability by attaching a mid-water float 13, which is tethered to the seabed with a connector 17. The grouping of the structures in this combined way together with carefully selected tether 12 design can be adjusted to suit localised wave conditions 18. For example, by selecting the distance 14 between the structures to coincide with an odd number half wavelength multiple, the wave forces on the structures will be out of phase as shown by arrows 15 and 16, and thus the motion of the structures will be out of phase. The arrows under the wave surface 18 show the relative direction of the water particles due to the wave phase. The tether 12 stiffness and pre-tension can be designed so that motion of one structure results in a damping of the motion in another structure.

CLAIMS

1. A floating wind turbine or general equipment installation and support structure comprising a watertight hull formed of concrete, ferrous cement, fibre-reinforced concrete, steel or other suitable material, a gravity or suction foundation comprising one or more components located at or on a lakebed or seabed, one or more buoyancy devices connected to said watertight hull and configured to provide excess buoyancy and additional stability, the watertight hull and buoyancy device assembly being tethered to said foundation such that the excess buoyancy is manifested as a force in the tethers, said tethers thus remaining taut and providing additional stability, and a shaft which extends upwardly from the hull, said shaft being telescopically extendable, with a hoist located at the shaft top.

2. A floating wind turbine or general equipment installation and support structure as claimed in Claim 1 wherein the buoyancy devices consist of cylindrical vessels with domed ends, and are attached to the structure with steel tubular sections.

3. A floating wind turbine or general equipment installation and support structure as claimed in Claim 1 or Claim 2, wherein air or gas pressurisation of the buoyancy devices may be used to ensure internal pressure therein is greater than external, thus limiting the requirement for internal stiffening of the chamber.

4. A floating wind turbine or general equipment installation and support structure as claimed in Claim 1 wherein the excess buoyancy is provided with a single hull to which the shaft and tethers are attached.

5. A floating wind turbine or general equipment installation and support structure as claimed in Claim 1 or Claim 4, wherein the tethers are connected by means of horizontal outriggers to increase righting moments in the buoy system.

6. A floating wind turbine or general equipment installation and support structure as claimed in any preceding claim, wherein ballast containers are fitted to the mast at various levels to allow for control of vibration of natural frequencies if required.

7. A floating wind turbine or general equipment installation and support structure as claimed in any preceding claim, wherein the foundation comprises a gravity base or suction caissons, and can be used to aid flotation during tow out and installation.

8. A floating wind turbine or general equipment installation and support structure as claimed in any preceding claim, wherein the foundation can provide a template / guide to aid tether installation.

9. A floating wind turbine or general equipment installation and support structure as claimed in any preceding claim, wherein the tethers can be used to lower the foundation to the lakebed or seabed during installation

10. A floating wind turbine or general equipment installation and support structure as claimed in any preceding claim, wherein lengths of chain or other linearly adjustable system are

attached between the tethers and winches on the structure to allow for variations in water depth during installation.

11. A floating wind turbine or general equipment installation and support structure as claimed in any preceding claim, wherein a wind turbine is located at the top of the shaft prior to installation.

12. A floating wind turbine or general equipment installation and support structure as claimed in any of claims 1 to 10, wherein the structure is used to install and support general equipment for use offshore, for example telecommunications equipment, pollution detection equipment, gas flaring equipment, or monitoring equipment.

13. A floating wind turbine or general equipment installation and support structure as claimed in any preceding claim, wherein a water turbine assembly is suspended under the hull, with additional support provided by slidable linkages connected from the turbine to the tethers.

14. A floating wind turbine or general equipment installation and support structure as claimed in Claim 13 wherein the water turbine is driven by current and wave loading, and can be raised or lowered to facilitate maintenance.

15. A floating wind turbine or general equipment installation and support structure as claimed in any preceding claim, wherein the shaft is fully retracted during tow out, and foundation ballast and installation operations.

16. A floating wind turbine or general equipment installation and support structure as claimed in any preceding claim, wherein an additional tubular shaft (lower) is designed to be fitted with ballast and to be extendable beneath the hull.

17. A floating wind turbine or general equipment installation and support structure as claimed in any preceding claim, wherein the annular space between the tubular shaft and the hull is grouted to provide a rigid connection for the telescopic shafts once in the fully extended position for both the upper and lower shafts.

18. A floating wind turbine or general equipment installation and support structure as claimed in any of claims 1 to 16, wherein clamping devices are used to facilitate subsequent lowering of the mast for maintenance or removal.

19. A floating wind turbine or general equipment installation and support structure as claimed in any preceding claim, wherein steel or other suitable material rods or wires are connected parallel or at an angle to the tubular mast structure (extended shaft) attached to spacers located at several positions along the axis of mast.

20. A floating wind turbine or general equipment installation and support structure as claimed in Claim 19 wherein the rods or wires are pre-stressed.

21. A floating wind turbine or general equipment installation and support structure as claimed in Claim 19 or Claim 20, wherein a tensioning device is used to cyclically pre-stress the support rods, the tensioning device may be hydraulic, electrically operated or mechanical.

22. A floating wind turbine or general equipment installation and support structure as claimed in Claim 20 wherein a load detection device is employed in conjunction with the tensioner such that the tension is adjusted relative to the external applied load to reduce mast motion or stress levels and improve fatigue life.

23. A floating wind turbine or general equipment installation and support structure as claimed in any preceding claim, wherein a generator is located in the submerged hull and rotated remotely by hydraulic drive from the rotor.

24. A floating wind turbine or general equipment installation and support structure as claimed in Claim 23 wherein the generator is mounted with its axis vertical in the hull to enable the use of a very large diameter generator with subsequent improved power efficiency.

25. A floating wind turbine or general equipment installation and support structure as claimed in any preceding claim, wherein the rotor blades are fixed to the turbine axle subsequent to the installation of the support structure and to the shaft being partially or fully extended.

26. A floating wind turbine or general equipment installation and support structure as claimed in any of claims 1 to 24, wherein the rotor hub and blades are hinged to the top of the shaft at a horizontal angle enabling said hub and blades to be fitted to the structure prior to tow out and foundation installation.

27. A floating wind turbine or general equipment installation and support structure as claimed in Claim 26, wherein the blades are hinged to the rotor hub and a hydraulic jacking mechanism is provided such that the blades can be rotated into horizontal alignment.

28. A floating wind turbine or general equipment installation and support structure as claimed in any preceding claim, wherein the hoist is used to position the rotor hub and blades in the desired vertical position after foundation installation and shaft extension operations.

29. A floating wind turbine or general equipment installation and support structure substantially as herein described and illustrated in the accompanying drawings.

30. A method of combining two or more floating wind turbine or general equipment installation and support structures to enhance dynamic stability in the combined system, the structures each having a watertight hull, a gravity or suction foundation located at or on a lakebed or seabed, one or more buoyancy devices connected to said watertight hull, the watertight hull and buoyancy device assembly being tethered to said foundation such that excess buoyancy is manifested as a force in the tethers, said tethers thus remaining taut and providing additional stability, and a shaft which extends upwardly from the hull, said shaft being telescopically extendable, the method comprising the interconnection of one or more of the structures by horizontal or nearly horizontal flexible connectors, said connectors having a stiffness and pretension selected to ensure that horizontal restraining forces acting between the floating structures are transferred through the connectors in partial or complete opposition to the environmental loadings to which each structure is independently subject.

31. A method of combining two or more floating wind turbine or general equipment installation and support structures as claimed in Claim 30, wherein adjacent connected structures are placed at such a distance as to be subject as far as possible to a differing phase of the wave cycle at the same instant i.e. water particle velocity on each structure will have a different relative motion.

32. A method of combining two or more floating wind turbine or general equipment installation and support structures as claimed in Claim 30 or Claim 31, wherein an anchor structure is used to reduce the overall motions of the combined support structures.

33. A method of combining two or more floating wind turbine or general equipment installation and support structures as claimed in Claim 32, wherein the anchor structure consists of one or more mid water float chambers tethered to the seabed and tethered to one or more of the floating support structures.

34. A method of combining two or more floating wind turbine or general equipment installation and support structures as claimed in any of claims 30 to 33, wherein the method uses damping devices, e.g. springs, chains attached to the tethers between support structures or anchor and support structures in order to influence the stiffness and motions of the system.

35. A method of combining two or more floating wind turbine or general equipment installation and support structures substantially as herein described and illustrated in the accompanying drawings.

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Application No:	GB 0205207.4	**Examiner:**	Richard Collins
Claims searched:	1 to 29	**Date of search:**	8 October 2002

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.T): B7A AAAQ; E1H HB; F1T TDC.

Int Cl (Ed.7): B63B 35/44.

Other: Online EPODOC, JAPIO, WPI.

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
Y	GB 2365905 A	(BONE) see figure 1 and related description.	1,4,15
Y	US 5609442 A	(HORTON) see figures 1 and 2 and related description.	1,4,15

X Document indicating lack of novelty or inventive step	A Document indicating technological background and/or state of the art.
Y Document indicating lack of inventive step if combined with one or more other documents of same category.	P Document published on or after the declared priority date but before the filing date of this invention.
& Member of the same patent family	E Patent document published on or after, but with priority date earlier than, the filing date of this application.

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Application No:	GB 0205207.4	**Examiner:**	Richard Collins
Claims searched:	30 to 35	**Date of search:**	10 December 2002

Patents Act 1977 : Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
A	-	US 5609442 A (HORTON) see figures 1 and 2 and related description.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^T:

B7A; E1H; F1T.

Worldwide search of patent documents classified in the following areas of the IPC^7:

B63B.

The following online and other databases have been used in the preparation of this search report :

EPODOC, JAPIO, WPI.